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Design of Dual Core Photonic Crystal Fiber (DC-PCF) Based Temperature Sensor with Rectangular Lattice Structure

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***Abstract*: In this paper, a temperature sensor which is based on dual-core photonic crystal fiber (DC-PCF) with rectangular air-hole lattice structure is proposed. The two fiber cores of the PCF are separated by single air hole and the background material is taken as silica whose refractive index is 1.45. The temperature sensitivity can be achieved 0.905 nm/^{o}C for the sensing range from 0 to 1000^{o}C.**

Keywords- Dual core PCF, Temperature sensor, Mode coupling, sensitivity.

1. INTRODUCTION

In the recent years, a rising number of PCF refractive index sensors for various applications like pressure sensor [1], refractive index sensor [2], bio and temperature sensor [3, 4], etc. In most PCF based sensors, only single fiber core was used. When the number of fiber cores is more than one, which increases the RI detection range. In detail, dual-core PCFs have a large number of applications, enticing a lot of researcher's interest. Because of their flexible design and easy fabrication, DC-PCF have showed numerous advantages in the applications of optical communication and sensing [5-7]. Dual-core PCF have also showed very good performances in many other applications like narrow band-pass filter [8], PCF coupler [7,10], polarization splitter [9], and wavelength Mux-DeMux [11].

In this paper, we have proposed fiber having two cores which are separated by single air hole for temperature sensing.

The configuration of the proposed DC-PCF is designed by COMSOL Multiphysics software which is based on FEM. The working principle of dual-core PCF for temperature sensing is based on thermo optic effect which is thermal modulation of r.i. of a material.

2. PCF DESIGN

The proposed PCF consists of a periodic array of rectangular air holes lattice structure, here we take diameter of circular air holes are $d = 1.4$ µm, pitch $\Lambda = 2$ µm and the background material of proposed PCF is taken as silica. We consider the refractive index of silica and air is 1.45 and 1 respectively. The geometry of proposed DC-PCF is shown in figure 1.

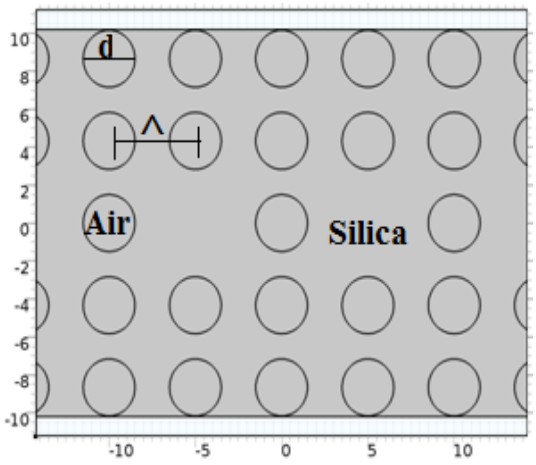

Fig.1 Geometry of proposed dual-core PCF.

DC-PCF coupling can be explained by four super modes in the *x*-y polarization. These four super modes can be created due to the separate cores. Fig.2 shows the distribution of electric field of the four super modes at 1.55 µm.

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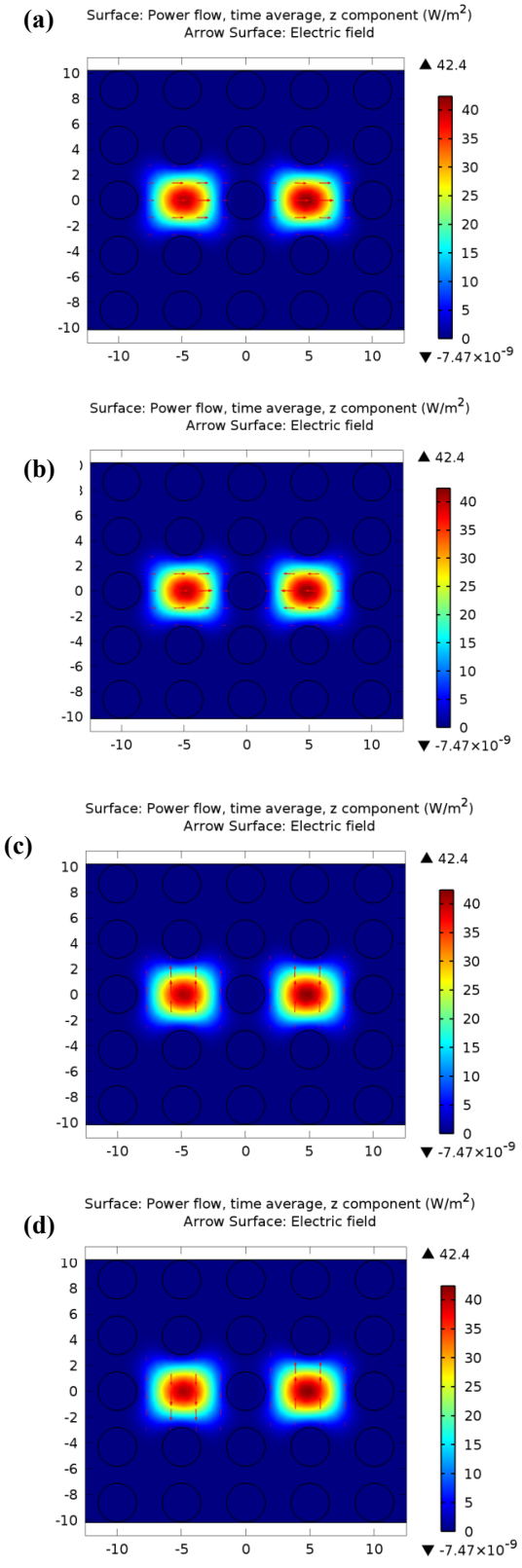
(a)
Surface: Power flow, time average, z component (W/m²)
Arrow Surface: Electric field
(b)
Surface: Power flow, time average, z component (W/m²)
Arrow Surface: Electric field
(c)
Surface: Power flow, time average, z component (W/m²)
Arrow Surface: Electric field
(d)
Surface: Power flow, time average, z component (W/m²)
Arrow Surface: Electric field
▲ 42.4
▼ -7.47×10⁻⁹

Fig.2 Distribution of electric field of the four super modes: (a) x polarized even (b)x polarized odd (c)y polarized even (d) y polarized ODD mode.

The coupling length of the DC-PCF is defined as [5, 10]

$$L_c = \frac{\pi}{|\beta_e^i - \beta_o^i|} = \frac{\lambda}{2|n_e^i - n_o^i|}, \qquad \text{i} = \text{x, y} \qquad (1)$$

Where, even and odd mode propagation constants represent as β_e^i and β_o^i respectively. The effective refractive indexes of even and odd mode represent as n_e^i and n_o^i respectively. By using Eq. (1), we have calculated the value of coupling length for different diameter. Firstly, we calculate the refractive indices of four super mode and then effective refractive indexes difference for *x-y* polarized light has been calculated, after that, their coupling lengths have been calculated.

The power transfer of DC-PCF after a length L is calculated as [10]

$$\mathrm{I}(\lambda) = \sin^2\left(\frac{\pi}{\lambda}\Delta n_{eo} L\right) \qquad (2)$$

Where, $\Delta n_{eo} = \left|n_e^i - n_o^i\right|$ and effective refractive indexes of even and odd mode represent as n_e^i and n_o^i respectively.

For the sensor purpose, we calculate the temperature sensitivity of the dual-core PCF by shifting of the peaks when the temperature is increased for the sensing range from 0 to 1000ºC. The temperature sensitivity of the DC-PCF is defined as [12]

$$S_\lambda(nmRIU^{-1}) = \Delta\lambda_{peak}/\Delta\mathrm{T} \qquad (3)$$

Where the shift of the transmission spectra is represents as $\Delta\lambda_{\text{peak}}$ and ΔT represents the different temperature for the sensing range from 0 to 1000ºC.

According to thermo-optic effect when we apply the heat on the fiber, the value of r.i. will be changed very little over normal temperature. The thermo-optic coefficient of silica is calculated by [13]

$$\frac{dn}{dt} = 10^{-5}(1/^{O}C) \qquad (4)$$

Refractive index of silica for DC-PCF with temperature is

$$n = 1.45 + T10^{-5} \qquad (5)$$

3. RESULTS AND DISCUSSION

In this paper we have numerically calculated the effective refractive index for even and odd modes are 1.403322 and 1.402997 respectively at 1.55 µm. Figure 3 shows the effective refractive index

variation of even and odd mode for *x*-polarized with wavelength. When we increase the wavelength, effective refractive index is decreases.

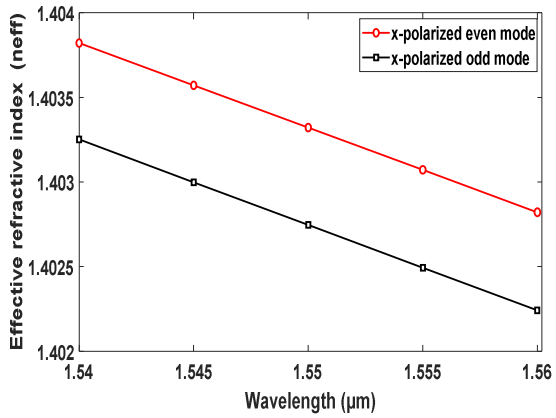

Fig.3 Effective refractive index variation with wavelength when d = 1.4 μm.

Figure 4 represents that the effective refractive index difference (Δn_{eo}) variation, which is $\Delta n_{eo} = |n_e - n_o|$. Δn_{eo} is increases when the wavelength increases, because the difference of effective index between the cladding and core is higher and the light is confine more strongly into the core.

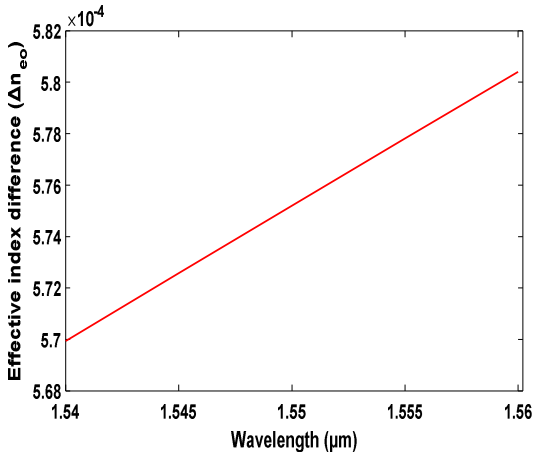

Fig.4 Effective refractive index difference with wavelength at d = 1.4 μm.

Figure 5 shows the coupling length variation with diameter. By using Eq. (1), we have calculated the value of coupling length for different diameter. First, we calculate the refractive indices of four super mode and then effective refractive indexes difference for *x* and *y* polarization has been calculated, after that, their coupling lengths have been calculated from the Eq. (1). The coupling lengths of DC-PCF vary with diameter. We have to see that coupling length of x-polarized light is smaller than y and when we increase the diameter the coupling length is increases.

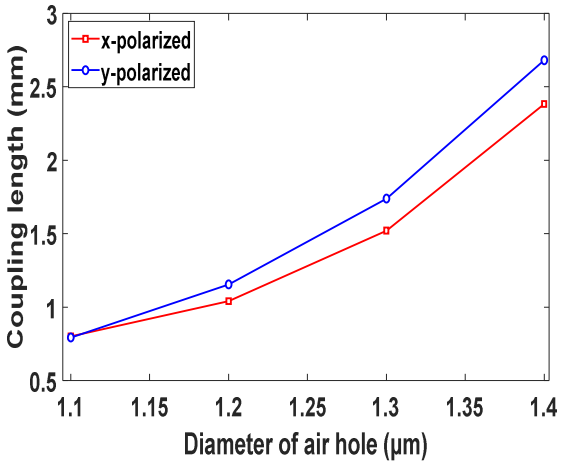

Fig.5 Coupling length variation with diameter.

Figure 6 shows power transmission curve of DC-PCF for the *x*-polarised light with a length of 1 cm under the temperature 0ºC, 200ºC, 400ºC, 600ºC, 800ºC, 1000ºC respectively. The power transmission curve of the proposed PCF is sinusoidal.

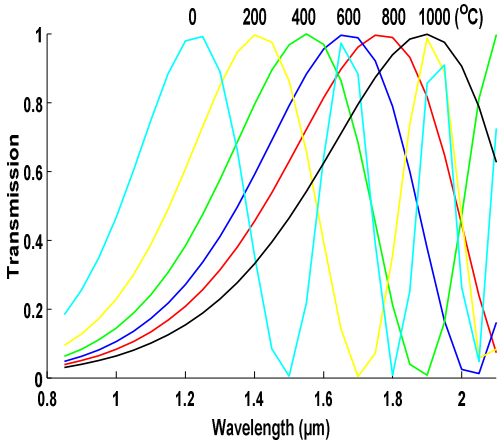

Fig.6 Power transmission for the *x*-polarized with different temperature at length 1cm

Figure 7 shows the numerical shift of the peak wavelength when the temperature is increased for the sensing range from 0 to 1000ºC. It can be seen that the curve is linear and when we increase the temperature the transmission curve is shift to the higher wavelength. The temperature sensitivity of the dual-core PCF can be achieved 0.905 nm/ºC for 1cm fiber.

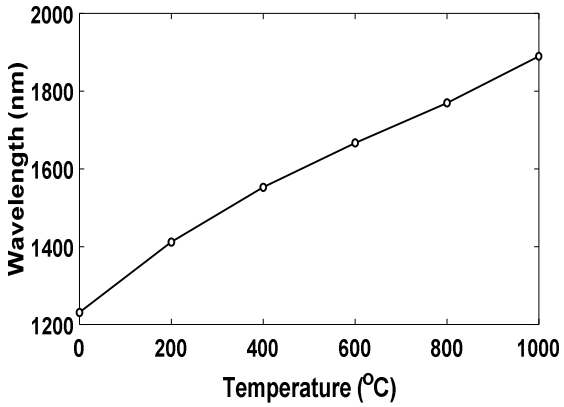

Fig. 7 Numerical result of function between ΔT and λ_{Peak} (nm).

4. CONCLUSION

In this paper we proposed a temperature sensor which is based on DC-PCF by using COMSOL software. The temperature sensitivity of the DC-PCF can be achieved 0.905 nm/°C for 1cm fiber under the 0 to 1000°C temperature sensing range. Low cost, compact in size and superior stability are the main advantages of DC-PCF based temperature sensor.

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